Art. XXXVI.—*The Structure and General Geology of the Warrandyte Goldfield and Adjacent Country.*

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(With Plates XCI.–XCIII.).

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Contents.

Introduction.

The area dealt with in this paper, as shown on one of the accompanying maps, consists of the whole or parts of the Parishes of Nillumbik, Sutton, Warrandyte, Ringwood, Bulleen and Nunawading, and is on a very rough approximation about 130 square miles. The greater portion of this district has been the subject of detailed mapping by the writer. The observations recorded and the conclusions drawn in this paper are based on this work, and therefore it will be understood that although from considerations of space the details cannot be shown on the attached maps, almost the whole of the available evidence has been obtained.

As some time must elapse before the detailed survey can be completed, and before the fossils collected and to be collected can be determined, the results to date are now brought forward.

It is hoped that the detailed map will be published later, and that sufficient palaeontological evidence may then have been obtained to adequately discuss the stratigraphy of the area.

The rocks of the district are mainly silurian sediments, and it is with them only that this paper is concerned. Some of the other formations will be considered in a separate paper; and the physiography is being similarly treated. It is sufficient here to state that the silurian rocks form a moderately dissected peneplain a few hundred feet above sea-level. The roughest ground is perhaps at Warrandyte.

Over a considerable portion of the country south of the Yarra, I have had the great advantage of the excellent topographical map prepared in 1893 by Mr. R. A. Moon. Apart from this map, one has to rely on the parish maps, which, for detailed geological work, are very insufficient; and where a series of observations has to be definitely located, rough surveys must be made. This was my experience in connection with the Warrandyte goldfield, which is mainly outside the boundaries of Mr. Moon's map. A comparison of the physical features shown on the attached Warrandyte goldfield map to the north and the south of the Yarra, shows the poverty of in-

formation on the parish map and the completeness of Mr. Moon's.

The necessity of more accurate topographical maps being prepared requires emphasis, as no entirely satisfactory detailed geological work can be done without much more correct and more complete maps. The various parish maps do not always fit together, and in compiling a larger map one has to take the mean of the discrepancies.

Previous Literature.

In 1855-56 Selwyn (1) examined the basin of the Yarra as far as where Warburton is now located, and showed that the bulk of the sedimentary rocks were palaeozoic (silurian), that they had been thrown into a series of anticlines and synclines, that auriferous quartz veins occurred, and that a conglomerate and breccia (both fossiliferous) were found at Anderson's Creek. His estimate of the thickness and relative age of the various beds will be mentioned subsequently in treating those subjects. The remarkable map accompanying Selwyn's report will always be the basis for all future work in the Yarra Basin.

In 1855 William Blandowski (2) briefly described and figured some fossils from Anderson's Creek.

In 1866 Selwyn (3, p. 12) referred again to the fossiliferous breccias. The geological sketch section accompanying his report showed the silurian beds from Yan Yean to Mt. Juliet folded into a succession of anticlines and synclines.

In 1893 Mr. R. A. Moon (4) made a topographical and geological survey of a large area of the country to the south of Warrandyte, which is included in this report. From a topographical standpoint this map is of great value. Every gully and every hill and ridge are shown with great accuracy, and in traversing the country I could fix any position with the utmost precision. Mr. Moon's available time was evidently so absorbed with the topographical work, and with indicating quartz reefs, that he was not able to deal much with the general geology. No serious attempt was made to grapple with the structure of the district (although he indicated a probable line of anticlinal from Tunstall to near Warrandyte,

with another short anticlinal line, and various dykes); and sections that required care and time to correctly determine were (wisely, I think, under the circumstances) omitted. In addition, since the issue of the map many more road and quarry sections have probably become available. Many sections, however, that could easily be missed were recorded by Mr. Moon, and it is a pleasure to acknowledge my indebtedness to him in this direction, and for the topography.

In 1894 Mr. R. A. F. Murray (5) reported on a brief inspection of Panton Hill, Queenstown, and other localities, and referred to the anticlinal fold along which at Warrandyte and Anderson's Creek, the principal gold discoveries had been made.

In 1895 Mr. James Stirling (6) briefly reported on the parishes of Warrandyte, Nillumbik, Greensborough and Queenstown, which had been rapidly surveyed by Mr. O. A. L. Whitelaw. Some sketch geological maps were issued, but the parish of Warrandyte was not included.

In 1896 Mr. Murray (7) reported briefly on the reefs at Warrandyte, and on an auriferous dyke on the south side of the Yarra.

In 1898 Mr. Walter Forbes (8) showed that the Warrandyte mining belt of country formed a series of anticlines and synclines, which he represented by map and section. He mentioned that bands of conglomerate were noticeable, referred to two auriferous dykes, and gave particulars of the strike, thickness, yields, etc., of the reefs. He also drew a section across the goldfield showing the numerous folds, but without reference to the structure of the surrounding country.

In 1902, Professor Gregory (9), in subdividing the silurian rocks of Victoria into the Melbournian and Yeringian series, referred to a great anticlinal, which he called the Warrandyte anticlinal, the axis of which passed through Warrandyte. He stated that along this axis was a line of contortions and faults (the "Warrandyte Fracture Zone"), along which a series of auriferous quartz reefs occurred. He classified the beds forming the Warrandyte Anticlinal as of Melbournian age (Ib. fig. 5, Plate XXV.).

In 1905 Mr. E. J. Dunn (10) reported on the Caledonia Gold Mine, with brief references to other reefs.

In 1907 Mr. A. M. Howitt (11) reported briefly on some reefs at Warrandyte, and noted a fossiliferous locality, and a basic dyke.

The Silurian Rocks of the District generally.

(a) *Area.*

With the exception of the older basalt at the Kangaroo Ground and some tertiary gravels, silurian rocks occupy the whole of the country here dealt with.

(b) *Petrology.*

The rocks of the district show little variation in lithological character. They consist mainly of shales with sandstones of varying degrees of coarseness. The shales are perhaps the most predominant. Throughout wide areas they are thick-bedded and massively jointed, as well as extremely rubbly. Bands of sandstone, generally from 3 to 12 inches thick, are sparsely interbedded with them. Occasionally sandstone bands up to 6 or 8 feet in thickness are met with; but they, as well as continuous sections of the same rock, are rare. Mica (generally muscovite) is extremely common in both the shales and sandstones, but in the latter rocks the flakes are larger, and therefore more noticeable. Many of the shaly rocks are when undecomposed, moderately tough, but on exposure they soon soften and break up.

The sandstones have been so silicified in places as almost to have become quartzites. Almost the only rocks that can be called quartzites occur in a narrow band of rocks running from the "Kopje," through Burt's Hill, and along the western side of Brushy Creek. Silicification has occurred all along this line, but only in parts have true quartzites been produced. The grains of the rocks in this band are finer than in most sandstones elsewhere met with. Slates are almost wholly absent from the district.

In the immediate neighbourhood of Warrandyte, conglomerates, grits and coarse sandstones are associated with the shales. The coarse-grained rocks outcrop on the ridges and slopes, par-

ticularly at Fourth Hill, a long ridge forming the crown of the main anticlinal fold of the district, along the axis of which most of the principal quartz reefs occur. An erroneous impression is likely to be obtained that these coarse-grained rocks are the predominant ones; but a careful inspection of the country and a glance at the mining dumps show that the shales and sandstones are by far the most common. Dr. T. S. Hall (12, p. 58) has referred to a somewhat similar instance at Castlemaine, although there is little accumulation of loose blocks in the valleys at Warrandyte. The coarser-grained rocks however, where they form a moderate proportion of the strata, largely determine the rate of denudation of the hills.

The conglomerates and grits vary in thickness from a few inches to about 12 feet. With one exception they cannot on the surface be traced more than about 100 yards, and usually less than that. In most cases they seem to pass rapidly into sandstones and shales, both along their line of strike, and in their vertical succession. Alternating sections are common. The rocks vary from fine grits to conglomerates, containing pebbles up to 3 or 4 inches in diameter. In the coarser rocks the pebbles are well rounded and water-worn. In the grits they are angular, and appear to have travelled little distance. The pebbles are of quartz, quartzite, sandstone, and flint or chert, quartzites perhaps being as abundant as any rock. Most of these rocks, as well as some sandstones and shales, are calcareous; but much of the lime has been leached out. The conglomerates are in places exceedingly tough; and project in boulders above the surface of the ground. Others are soft and friable, and would not be noticeable except for artificial sections. Quartz veins occur, but usually about $\frac{1}{8}$ or $\frac{1}{4}$ of an inch thick, and in the hardest conglomerate are almost absent.

The only conglomerate that can be traced any distance is one seen in section in Whipstick Gully, near the Victory mine. It is here about 12 feet thick, and is a tough, dense grey rock when fresh. It differs from most conglomerates of the district in having comparatively few, but always well-rounded, pebbles set in a fine matrix. This, and its mode of weathering into large boulders, enable it to be readily traced. It is found on both sides of Whipstick Gully and of Anderson's Creek. Its

distribution will be dealt with when treating of the geological structure. Almost all the coarser-grained rocks are fossiliferous

(c) *Geological Structure.*

Folds.—The principal structural features are the anticlines and synclines, into which the whole of the silurian rocks of the district have been thrown. There are great folds which embrace a wide area, and which can be traced along the strike of the rocks considerable distances. Sometimes they give place to smaller but more numerous folds. The main anticlinal lines at times bear on their crests smaller folds, which in some instances are not very much compressed, the legs being at moderate angles; in other cases the pressure has been so great that the legs are almost vertical, but no example of inversion has been observed. The minor folds seem to soon run out along the strike of the rocks. Where there is a main anticlinal fold, with numerous smaller ones on its crest, fracture of the rocks, as would be expected, has taken place, and so channels have been opened for the deposition of quartz, gold and other minerals. The generally short courses of the subsidiary folds probably account for the restriction of quartz reefs in a meridional direction. The general strike of the rocks would average about 15 deg. east of north.

Treating the folds in more detail, a traverse from Templestowe through Warrandyte to the north of Croydon shows that at Templestowe an anticline, which, in its principal or subsidiary folds, has been traced south to the Koonung Koonung Creek, and north to the northern boundary of the parish of Nillumbik (crossing the Diamond Creek to the south of the township of that name), a distance of nine miles. At Templestowe two sharp minor anticlines occur, which may be regarded as folds in the main axis. The reef containing gold and antimony, that has been worked at Templestowe with unfortunately, (in recent times at least), non-payable results, probably occurs on one of the minor anticlinal folds. The western limb of the anticline is much contorted in places, as may be seen on the main road between the Plenty River and Eltham, and on the Eltham railway line. The anticline here described may conveniently be referred to as the Templestowe Anticline.

The next fold to the east is that of the great syncline, whose axis crosses the Yarra River between the Diamond and Mullum Mullum Creeks. It has been traced for the same distance and between the same boundaries as the Templestowe Anticline. This structural feature has been named the Bulleen Syncline, from the parish in which it is so well developed. It is a broad fold, having a great thickness of rocks developed in its septa, particularly the eastern one. From the axial line, the westerly dip can be traced right into Warrandyte township, a distance of four miles in a straight line. This septum forms the western leg of the next great anticlinal fold, that already known as the Warrandyte Anticline.

This fold consists of one great arch, with five minor anticlines and four minor synclines on its crown at Warrandyte. In this district it is a geanticline, but this feature is not retained either to the north or to the south. These minor folds comprise Professor Gregory's "Warrandyte Fracture Zone," and scarcely extend beyond Anderson's Creek, Parson's Gully and the Yarra, except where one becomes the main axis to the north or the south.

The eastern leg of the Warrandyte Anticline has been traced with a regular easterly dip from Warrandyte south-easterly to a little to the north of Croydon, a distance of about 3½ miles; and may possibly extend farther eastward. In this limb the amount of dip keeps fairly constant; but in the western leg, minor puckers and nearly horizontal strata occur, which indicate lateral pressure of insufficient strength to form more folds. At Melbourne Hill, near Warrandyte, on the old main road, and on the main Warrandyte-road, just east of Newman's-road, miniature anticlines and synclines, and strata of low dip are exposed. Rocks nearly horizontal also occur along the Yarra west of Pound Bend, and in a series of quarries along Ruffley's Creek. These features however do not affect the general westerly dip. The eastern limb of the Warrandyte Anticline is generally of higher dip than the western in the locality under consideration. The latter would perhaps average about 40 deg. and the former about 60 deg. This would tend to incline the axis to the west, which is what actually occurs at the Caledonia Mine, according to the surveys of the mine.

The Warrandyte Anticline extends, so far as my observations go, from Tunstall to the north-east corner of the Nillumbik Parish at Watson's Creek, a distance of twelve miles; but it does not consist of one unbroken axial line, nor does it retain the great thickness of its septa, which, as already stated, exists to the east and west of the axis at Warrandyte.

Taking the minor folds of the crown of the anticline from their western side, the first and second anticlines are the only folds that can be traced any distance to the north or the south; and these really constitute the main axis of the great arch. The second one, which carries the main line of gold workings at Warrandyte, may be followed to Tunstall, where it becomes one of several normal folds. Northerly it crosses the Yarra to the west of the island, and is traceable further north to the large bend in the Yarra near the Caledonia Mine. Here it may be thrown to the east by a fault, and if so, as shown on the map, its further course is short and it dies out altogether.

The main axial line of the Warrandyte Anticline appears to be continued to the north in the first minor anticline. This commences a little south of the Yarra, and has been traced to Watson's Creek at the north-west corner of Nillumbik Parish. Its further extension has not been observed. From being a minor fold at Warrandyte, it rapidly becomes a great anticline, which does not however retain its geanticlinal features, nor the great thickness of both limbs, as the section along the line AB of the map of the whole area shows. Between the axis of this anticline and that of the Bulleen Syncline, a normal syncline and anticline occur. The eastern limb has a thickness of about 8000 feet, and its limit has not yet been determined. This limb is disclosed in two splendid sections, about one mile and one and a quarter miles in respective lengths, along the Maroondah Aqueduct. The gap between these sections is filled by the dips available at Watson's Creek, and thus a practically continuous section about three miles in length is obtained. This section is remarkable for the great regularity and unbroken character of the strata. This feature is applicable to the limbs of the folds in the district generally. Intense squeezing has taken place fairly often, but it is as a rule restricted to the axial lines, and generally to the anticlines. From casual

observation, it might be thought that the structure was often hopelessly tangled, but detailed examination proves that this is not so. The other minor folds of the Warrandyte Anticline are short and restricted to the vicinity of Warrandyte. The dips along the line of dyke east of the Caledonia, and also of the country further east, are all easterly with generally a north-westerly strike, thus converging towards the strike of the axis of the second minor anticline. On the northern bank of the Yarra opposite the Caledonia Mine, the dips are not too clear, but so far as they go, the two converging lines of strike have met here to form a single fold, with the minor folds to the south and east cut out. This single fold is apparently faulted to the east; it then runs north-easterly for a short distance, but soon dies out, as before mentioned. The strike of the rocks however continues to the north-east.

The structure therefore at Warrandyte appears to be a great arch, on the crown of which are several minor anticlines and synclines. The two most westerly anticlines are preserved to form the main axis of the fold to the north and the south. This axis thus becomes disconnected at Warrandyte. The minor folds to the east of the main axis appear to merge into one fold to the north of the Caledonia Mine, giving a fan-shaped structure, the fan opening unequally from north to south. A strong northerly pitch near the river at Warrandyte has accentuated the structural form. By way of contrast, the structure may be considered along a line roughly parallel to the railway from Blackburn to Croydon, which shows a normal order. Beginning at the former place, there are, as shown on the map, the Blackburn Anticline, the Tunstall Syncline, the Warrandyte Anticline, the Mitcham Syncline, and the Ringwood Anticline, with other small folds further east. The named folds are normal to one another and regular, although some minor puckers are found on their axes. Thus the great arch at Warrandyte becomes in its southern portion split up into five normal folds at least.

The distinctive band of quartzitic sandstones occurs along the outer part of the eastern leg of the Warrandyte Anticline, and it is of interest to see how the strike runs north-easterly to Croydon, then gradually swings round to the north-west, and

is traced along Narrmeian Creek to the Yarra where, as before noted, the strikes converge and one fold results, after which the strike becomes north-east again.

Associated with the minor folds at Warrandyte are the conglomerates, grits and sandstones that have been already described. These conglomerates and grits, wherever observed, are conformable to shales and sandstones, and there is no evidence of any unconformity between the beds, nor can any base be detected.

The outcrops of the conglomerates are numerous, and occur on most of the folds, but the only distinctive one is that already referred to. This is found on both sides of Whipstick Gully and on the northern side of Anderson's Creek, folded round the axis of the second minor anticline, and passing into Third Hill and through Fourth Hill.

The axis of the fold at Whipstick Gully has a strong pitch, the crown of the conglomerate at the axial line being lower on the northern side than on the southern. This pitch probably accounts for its non-outcrop farther north.

The conglomerate has a steep easterly leg and a more gentle westerly one, thus illustrating the general nature of the main fold. On the left side of Anderson's Creek, a disconnected band of the conglomerate runs south-westerly parallel to the creek for about 200 yards. Its outcrop ceases at the next tributary gully; but whether from faulting or from passing into finer-grained rocks, cannot be stated. This band is, from the dips in the vicinity, on the eastern leg of the anticline, but is not in a direct line with that on the opposite side of the creek. The western leg does not outcrop, but may be covered by alluvium on the right bank of the creek. Faulting has probably occurred here, and caused a displacement of the conglomerate to the east; but it cannot be very much, as the axial lines of the anticline continue southward with practically no deviation.

This conglomerate has not been found on any of the other folds. This may be due to faulting, or to occupying a small area, or to a change in its lithological character, probably to one of the two latter, as faulting on a large scale does not seem to have much occurred.

With regard to pitch generally, in the southern portion of the area, no widespread pitch occurs. In places there is possibly apparently small local pitch, but this may be due to the running out of the anticlines or synclines, and not to crustal movements.

The pitch of the rocks at Warrandyte has been already noticed, and this pitch appears to continue north-easterly along the axis of the Warrandyte Anticline to Watson's Creek, a distance from Warrandyte of five miles. It is well seen where the axis crosses the Maroondah Aqueduct, at which point the beds are pitching to the north-east at an angle of 40 deg. At Watson's Creek the feature is repeated, the angle here being 35 deg. At the latter locality the sections are particularly instructive. Almost a semi-circle in the direction of the strike can be traced from the western leg of the anticline, through its axis to the eastern leg.

This strong pitch together with the eastern and western limbs of the Warrandyte Anticline, gives at Warrandyte three sides of a great dome. A strong southerly pitch towards Ringwood would complete the dome, but this does not exist. At one time such a pitch may have existed, but the latter may have been destroyed by subsequent differential movements. Of this there is no evidence, except that which may have formed the Mitcham Axis (details of which are given in the separate paper dealing with the physiography of the district), and which would probably not be sufficient to obliterate any pronounced pitch.

Faults.—These do not appear to be important. Numerous small dip faults occur at the Caledonia Mine, as will be described later. That in the conglomerate at Anderson's Creek is also a dip fault, but the horizontal displacement of the rocks may be calculated in yards. Strike faults probably occur in the mines along the reef channels. Casts of slickensides in quartz in various parts of the area outside Warrandyte prove movement. Most of the latter appears to have been vertical. That it at times was much from the vertical is shown by the almost horizontal slickensides noticed in some quarries on Ruffley's Creek. No evidence, however, of any movement that has caused a great displacement has been obtained. Although fractures are numerous in connection with the folds (as at Warrandyte),

yet much slipping does not appear to have taken place. This is shown by the repetition of the grits and conglomerates at Warrandyte, which from the general appearance of their fossil contents, and their lithology indicate their connection with one another. A possible line of faulting is the main dyke east of the Caledonia mine, which has been traced several miles, but for the reasons given when treating of the cause of the horizontal limitation of the Warrandyte field, this is probably a fracture with little displacement. The general structure of the country as above indicated, suggests that no important movement has taken place along this line.

An important fault, but belonging to a much later period than the folds and fractures of the silurian rocks generally, is marked on the map as the Brushy Creek Fault. This is fully dealt with in the paper on the physiography of the Yarra River and Dandenong Creek Basins, and need not be further discussed here.

Dykes.—The principal one is that noticed under the preceding section; a little to the east is another one. They are indicated on the accompanying maps so far as traced by the writer, but one, according to Mr. Whitelaw's geological map of part of the Nillumbik Parish, runs as far as Kangaroo Ground. They are about 8 or 10 feet wide and dip to the east, the more westerly one at 60 deg. and the other at about 45 deg. The rock is so decomposed that it cannot be determined. The dykes contain thin auriferous quartz veins. Other dykes are marked on Mr. Moon's Quarter Sheet, and others occur near Croydon, where they have been worked for kaolin.

Mr. A. M. Howitt (11, p. 40) discovered when at Warrandyte a basic dyke about 2 feet in width in the Caledonia Mine cutting across a cross-course. The rock was fairly fresh, and enabled Prof. Skeats to determine it as a monchiquite.

Joints.—These in general call for no special remarks. In most cases they do not pass continuously through different rock beds. Dip and strike joints are sometimes fairly well developed, and in thick-bedded homogeneous shaly rocks cause great difficulty in determining the dip. Some points of interest in connection with joints may be noted.

Some of the vertical joints are so close together that they have the appearance of incipient cleavage. At a quarry on the Mullum Mullum Creek, there is a band of rock about 2 feet 6 inches broad and about 15 feet high, divided into regular vertical lines from 1 to 3 inches apart. No other division planes are visible. On each side of this band ordinary well marked bedding planes are developed with vertical joints a little distance apart. On close examination similar rocks are seen to continue across the particular band. The jointing has been so minute and regular as to obliterate the bedding planes in this portion of the rocks. Curved joints are found above the entrance tunnel at Pound Bend. In no other locality in the area have I noticed similar joints.

The most interesting jointing is in connection with the conglomerates and grits at Warrandyte. Some of these rocks are fairly tough. When jointed, even in blocks 3 or 4 inches in size, the hard quartz, quartzite, chert, and sandstone pebbles are often seen to be cut through as smoothly and evenly, as if they were plastic materials cut with a knife. That this is simply due to jointing is shown by the absence of slickensides, and by the very small and close planes that occur. It proves that the force exerted was enormous. De la Beche (13, p. 628) notices the same feature in the conglomerates of the Old Red Sandstone in the County of Waterford, Ireland, where "huge masses of the conglomerate, composed of quartz pebbles and of portions of older arenaceous and other deposits, as also of igneous rocks, in certain localities, may be smoothly cut through and separated by joint planes." He also states that the division presents no trace of dislocation or movement, the faces of the divided parts of the pebbles fitting each other exactly. When the Warrandyte conglomerates are broken with the hammer, the fracture is irregular, leaving the pebbles intact.

(d) *Fossils and Conditions of Sedimentation.*

At Warrandyte in the coarser grits and conglomerates, fossils are often abundant. They consist mainly of corals and polyzoa, but the species are apparently not numerous. The old Victorian Geological Survey found some fossils in the finer grained rocks,

but they are presumably scarce. Outside the Warrandyte district a trilobite, probably an Illaenus, and some brachiopods and corals have been found. The fossils have not yet been examined, so little can be said with regard to them.

The sediments indicate that at Warrandyte there was an old silurian shore line, close to which the conglomerates, grits and sandstones were laid down. These are also interbedded with shaly rocks, the alternations often being very rapid, thus showing shallow-water conditions. To the south of Warrandyte these coarse rocks seem to gradually pass into those of finer grain. A strong pitch conceals their northward extension, while they do not occur to the east or west, by reason of passing beneath the great mass of rocks that form the Warrandyte Anticline. Possibly their extent horizontally was never very great. The direction of the old shore line cannot be indicated, and all that can be said at present is that it was probably not to the south.

On the top of the shallow-water beds is a great thickness of shales, occasionally separated by thin bands of sandstones. These by their general absence of coarser material (in one or two places a thin band of grit or conglomerate has been found) appear to have been laid down in moderately deep water. On the top of these in the Croydon district is the narrow band of silicified sandstones. In the western part of the area the thick shales are succeeded by rocks of the type seen near Melbourne, alternating sandstones and shales. From the great thickness of the shaly rocks, it is evident that there was a gradually-sinking shore line, with which however the sedimentation kept place, and so prevented very deep-water conditions from resulting.

(e) *Age and Thickness of the Rocks.*

Pending the examination of the fossils, nothing definite can be said as to the age of the rocks throughout the area. Prof. Gregory has indicated (9, Plate xxv. Fig. 5) that the rocks of the Warrandyte Anticline are of Melbournian age, and has also suggested (Ib. p. 172) that the Yeringian series might be expected to appear in the syncline to the west of the Warrandyte Anticline) i.e., the Bulleen Syncline).

In 1856 Selwyn (1, p. 11), referring to his section across country, part of which is included in this paper, stated on purely stratigraphical grounds that the lowest portion was exposed in an anticlinal axis west of the Diamond Creek (i.e., the Templestowe Anticline), and the highest beds occurred immediately east of the River Yarra and west of the River Plenty.

On the field evidence, without determination of the fossils, I should place the Warrandyte grits and conglomerates as the oldest, and, going westerly, gradually rising until the youngest would be along the axis of the Bulleen Syncline, although there is no evidence yet to state that these are Yeringian. The beds of the Templestowe Anticline would be between these two, and therefore of about the same age as the middle beds of the western limb of the Warrandyte Anticline. Mr. Chapman records (17, p. 66) *Chonetes melbournensis* Chapm., from near Templestowe, and he informs me that this fossil has not been found outside the Melbournian series. If the Templestowe beds are Melbournian, the Warrandyte beds may be still older, or perhaps some faulting has occurred at Templestowe which has not been detected.

South-east from Warrandyte, the beds should become younger, until the youngest of the area would occur a little to the north of Croydon.

As there is apparently no pitch along the Warrandyte Anticline between Warrandyte and Tunstall, the beds at the latter place, unless there be some undiscovered dip faults, should be about the same age as those at the former locality.

The strong pitch northerly of the same great anticline should bring beds younger than those at Warrandyte to the surface at Watson's Creek in the north-east corner of Nillumbik Parish. The thickness of the rocks disclosed by the pitch along the axial line has not been estimated, so that their approximate position in relation to the other beds cannot be stated.

The fossils will of course ultimately have to definitely settle these questions, in conjunction with the field evidence.

Concerning thickness, Selwyn (1, p. 11) states that the greatest ascertained thickness of the beds along his line of section is 10,900 feet. According to the writer's calculations,

along the main undivided limbs of the Warrandyte Anticline (south-east and west of Warrandyte) the thickness of the rocks on the eastern limb is between 14,000 and 15,000 feet (allowing an average inclination of 60 deg.), while on the western (allowing an average dip of 40 deg.), it is between 12,000 feet and 13,000 feet.

Future research, especially in palaeontology, may discover that the beds are repeated by faulting, and this would of course reduce the thickness. The sections, however, on which the estimates are based are very continuous, and faulting is the only feature that could reduce them. The folds are so broad that inversion need not be considered.

(f) *Denudation.*

Judged by the estimated thickness of the beds forming the Warrandyte Anticline, there has been a minimum denudation at Warrandyte, prior to the dissection of the present peneplain, of over 12,000 feet vertically.

(g) *Character of the Rocks from which the Silurian Derived.*

Conglomerates are always of interest in the light they shed on the derivative rocks. At Warrandyte many of the sandstones and grits contain such an abundance of mica (mostly muscovite) as to suggest their derivation from an igneous rock. No such pre-existing rock outcrops in the district, and the conglomerates, so far as examined, have not yielded any pebbles of it. The constituent pebbles consist of quartz, quartzite, sandstone, and flint or chert, quartzites and sandstones being perhaps most abundant. The sandstones consist mainly of quartz grains, and so throw little light on the subject. It is evident therefore that the rocks which were broken down to form the conglomerates consisted largely, if not wholly, of altered and unaltered sedimentary rocks. No trace of these has yet been discovered.

The Warrandyte Goldfield.

(a) *Geological Structure.*

The main features have already been indicated under the geological structure of the whole district. To briefly recapitulate, there is a great anticlinal fold (the Warrandyte Anticline), which has five minor anticlines, and four synclines on its crown. The quartz reefs are intimately associated with these minor folds, and as frequent reference will have to be made to the latter, it is as well to use distinctive names.

As mentioned above, the most westerly minor anticline is really the northern continuation of the main axis of the whole main anticline, and the next minor anticline to the east occupies a similar position in the south. These minor folds have in the description of the geological structure of the district been referred to as the first minor anticline, and the second minor anticline, respectively. The most westerly fold can be called the Main North Anticline, and the next easterly anticline similarly the Main South Anticline, both being parts of the Warrandyte Anticline. It is in connection with the portions of the folds at Warrandyte that the terms suggested will be chiefly used. The short syncline between the two folds mentioned need not be named. Following the Main South Anticline to the east is the Caledonian Syncline, then Thomson's Gully Anticline, then a short synclinal axis, which requires no name, then the Consols Anticline, then an unnamed short syncline, and lastly the Fifth Hill Anticline. The names used (except for the first two anticlines) signify the reefs or physical features with which the folds are respectively connected. The enlarged map of Warrandyte shows the directions and lengths of the folds as traced.

The general relations of the minor folds to the major one have already been discussed. It will be noticed that the three anticlines east of the Main South Anticline tend to approach the latter and one another as they are followed to the north, and also that from west to east they become shorter at their

northern ends. The explanation appears to be that the lateral pressure which produced the folds, produced different results. At Warrandyte a great arch was formed, but the pressure continuing, the strain was relieved in one part of the field by the wrinkling of the crown of the arch. A little to the north, great pressure seems to have come from the east, with the result that the strata of the eastern leg of the great fold were bent towards the central axis, and acquired a north-westerly strike, losing their normal strike, which is north-easterly. The several small folds which occur to the south, appear to have been squeezed towards one another, and eventually to have merged in the northern continuation of the Main South Anticline. Farther to the west the fold of the Main North Anticline commenced. This anticline, where it overlaps the Main South Anticline, may be due to the pressure from the east already mentioned.

To the north of the area where the strata are squeezed to the north-west, the strike becomes north-easterly again, as shown along the Yarra towards Watson's Creek. The anticlinal axis which crosses a great bend of the river, as shown on the enlarged map of Warrandyte, although represented by a fine fold on the river bank, soon dies out to the north, whilst to the south, an east and west line would join the southern end (so far as traced) of this fold and the northern end of the Main South Anticline. This fact, together with the difference in the strike of the rocks, suggests a fault along this connecting line, caused by the intense pressure from the east, of the strata which now form the northern end of the Main South Anticline.

To the north of Warrandyte, the pressure relaxed, with the result that the axial lines widen, and the Main North Anticline develops into a broad fold with a western leg divided into two normal folds, whilst the eastern one is undisturbed and unfractured for several miles.

To the south of Warrandyte, normal folds have resulted without any intense folding or contortion.

At Warrandyte, therefore, the great pressure has caused the formation of a number of small folds along which, as would be expected, fracture has taken place. Thus Prof. Gregory's

"fracture zone" is justified, but the cause of that fracture zone, and its relations to the rocks of the surrounding country, have not hitherto been determined. The distribution of the quartz reefs, and their connection with the geological structure will be subsequently discussed.

(b) *The Quartz Reefs.*

These have been individually described in 1896 by Mr. Murray (7), and in 1898 by Mr. Walter Forbes (8). The latter gives full particulars of the reefs then known, as to strike, dip and thickness of beds, etc. It is therefore unnecessary to deal minutely with the reefs, even if that were possible, which it is not, as at the time of my visit to Warrandyte most of the later mines were closed down, and the old workings are as a rule inaccessible to any depth. The purpose kept in view during the examination of the country, was not to record minute information as to particular reefs, but to endeavour to grasp the relation of the reefs to geological structure, and by this means to throw some light on the cause of their distribution. A general account will therefore be sufficient, unless there be any points of special interest.

The reefs are associated with the minor folds, and generally with the anticlines, although the Caledonian and Bendigo lines are in the Caledonian Syncline. They are approximately parallel in strike to the direction of the axial lines, but at times cut across the strata at slight angles. Their strike varies from about N. 10 deg. E. to N. 25 deg. E. Their underlie is sometimes to the east and sometimes to the west, generally close to the vertical. They are usually thin, ranging from about 3 inches to 2 feet, the majority probably being under a foot in thickness. Most of the workings are shallow, not exceeding 200 feet in depth, and being very little below the ground-water level. The deepest mines are the "Victory" (whose greatest depth was about 275 feet) and the "Caledonia" (600 feet). The quartz is in places fairly well mineralised.

The lengths of the reefs, so far as ascertainable, appear to correspond in length with the folds of the rocks, or those portions of the folds that have been subjected to great pressure.

Thus the Main North Anticline dies out a short distance south of the Yarra, and no reefs appear to be there. North of the river, however, are the Loyal Liberal and other reefs, but the latter become scarce as the anticline widens out. The Main South Anticline has the main line of reef. It has been traced from the "Great Southern" reef (south of Anderson's Creek) through the Fourth, Third, Second, and First Hills to the northern side of the river, just west of the Caledonia mine. Farther to the north-east where the short anticlinal axis already referred to crosses a great bend of the river, a reef about 18 inches wide occurs. In the Caledonian Syncline two lines of reefs (the Caledonia, and the Black Swan-Bendigo lines) are traceable for a considerable length of the syncline. Thomson's Gully Anticline shows few workings, as the fold is short. The Consols Anticline has fairly continuous workings, and at Fifth Hill the reefs agree in length so far as traced.

A further point of interest is the distribution of the reefs in connection with the more westerly of the two auriferous dyke east of Warrandyte. This dyke runs in a north-westerly direction, and the reefs run from the south-west, and would meet the dyke if extended. So far as known, no reefs cross the dyke south of the river. The relations of the reefs to the dyke and to the folds will be discussed later.

The main line of reefs is mostly in the eastern leg of the Main South Anticline, but very close to its axis. Along the top of Fourth Hill, no well-defined reef has been worked, most of the workings being in thin apparently disconnected veins. The Caledonia is practically along the axial line of the Caledonia Syncline, while the Bendigo, Consols, and Fifth Hill lines are in rocks dipping westerly at the surface.

Various cross-courses have been described by Mr. Forbes. Some I have verified, others I have not from want of accessibility. These do not call for any detail. Thin-bedded veins are found in various parts of the field. Sometimes they fault the reefs, and are therefore subsequent to them. The reefs are generally moved only a few inches or a few feet. The bedded veins here indicate small movements along the bedding planes. These veins are said to have an influence in places on the deposition of gold, as will be mentioned later.

The mines that have been developed since Mr. Forbes' report are the Victory, the Caledonia and the Consols, which are now all closed down. Others, such as the Reward, North Caledonia, South Caledonia and the Blocks, were abandoned after very little work, so far as can be ascertained. The Consols is the old "Pigtail" reef, and the Victory has been worked mainly under Third Hill. The Caledonia is of interest structurally, and some details will therefore be given. For much of the information concerning the structure of the mine I am indebted to the plans of Mr. A. H. Merrin, M.C.E. (now Chief Inspector of Mines), and Mr. H. Herman, B.C.E., to both of whom I wish to tender my thanks for permission to refer to the same. The responsibility for the reading of the plans and for any conclusions drawn from them, is my own.

The Caledonia Mine has been reported on by Mr. Dunn, but since his visit the mine was much more opened up. The main shaft has been sunk to 600 feet, but little work has been done there, as the stone did not prove payable. The reef in the top levels underlies to the west, but turns to the east in the lowest level. I believe however that a winze showed that it soon became westerly again. It occurs in the Caledonia Syncline, whose axis dips from the vertical to the west. The rocks have a strong northerly pitch. Faults, cross-courses and "splices" occur in the first and second levels, and are almost wholly left-hand breaks (i.e., going north, the reef, where a break occurs, is found again to the west). The "splices" occur mainly in the top level, and the faults in the second. A "splice" consists of the reef, which when followed either to the north or the south gradually thins out, until it becomes a mere thread of quartz, and then completely dies out. If working northward, the miner cross-cuts to the west and begins to feel for the reef again. A thread of quartz is picked up, which, if followed, often gradually thickens into the reef and forms another splice. Fault planes do not as a rule exist between the splices. The strike of the faults is generally north-west and south-east, with the down-throw side (if the faults traced be normal) sometimes to the north-east and sometimes to the south-west, the latter oftener. With regard to the splices, we have instead of one continuous fissure, which forms the lode channel, a series of small,

independent fissures, each one (when followed to the north) more to the west than the preceding one. In these quartz has been deposited. The faults have moved the reef, and are therefore clearly subsequent to it, and consequently to the formation of the splices. These are the main structural points of interest in the mine.

(c) *Dykes.*

The two dykes east of Warrandyte have already been described. There are small irregular auriferous quartz veins in the rock, which at the surface is now decomposed to a clay. These quartz veins have evidently filled the cracks formed in the dyke rock on cooling, and are therefore subsequent to the intrusion of the dykes. The latter have been worked to shallow depths, and the results are given in the mining history of the field.

(d) *The Cause of the Horizontal Limitation of the Field.*

The Warrandyte goldfield occupies very little area. Few reefs cross the Yarra, and the latter may be regarded, roughly speaking, as the northern boundary of the field. On the west and south, Anderson's Creek (with some few exceptions a little to the south) is the boundary, whilst on the east, Parson's Gully and a line drawn to the east of the Caledonia Mine, form the remaining boundary. This peculiar limitation therefore calls for explanation.

The question involves the consideration of the relation of the reefs to the folds of the rocks, and the more westerly of the two dykes to the east of Warrandyte. As has been seen, the reefs appear to be connected with the folds, and to bear a distinct relation in regard to their horizontal lengths to the lengths of the folds. The dyke on the other hand has a direction and a position that suggest an influence on the lengths of the reefs. The view held by the local miners is that the dyke has in some way cut the reefs off. This could happen in two ways—viz., faulting and intrusion of the dyke subsequent to the formation of the reefs; and the formation of the dyke prior to the reefs, the former acting as a barrier to the latter.

Whether the dyke occupies a great fault, or merely a fracture, or a fault with little displacement, is an important question to decide. There is little evidence of a great fault.

In places the western wall appears somewhat smooth, but no striations or slickensides have been noticed. The rocks on opposite sides are slightly different lithologically, but a little slip could produce this. The dip of the strata on the western wall is not easily determined, but it appears to be the same as that on the eastern wall—i.e., to the east. The dyke meets the Main South Anticline near its northern termination, and this is rather peculiar, but on the other hand, if the dyke proceeds north-westerly to Kangaroo Ground, as shown by Mr. Whitelaw, it does not disturb the Main North Anticline, and the syncline to the east.

This fact and the structure generally support the contention as to the non-importance of the dyke structurally. The minor folds certainly tend towards a common point, and do not run parallel to one another towards the dyke. The strike of the eastern limb of the Warrandyte Anticline swings round from north-east to north-west, just as would be expected if the pressure on the eastern limb were very great at one point, and it was not much relieved by crumpling. In the least disturbed part of the eastern limb—i.e., south of Warrandyte—the dips regularly continue from west to east across the line of dyke. No appearance of faulting is here. As already remarked when discussing the quartz reefs, there seems to be a direct connection between the lengths of the minor folds and the reef occurrences.

On the whole therefore I think that the dyke in either of the two possibilities above suggested has had no influence in the general geological structure of the country, and hence none on the reefs so far as their distribution is concerned. The minor folds, with fractures as the result of great pressure, offer a solution of the distribution of the reefs. In no other parts of the area have well defined and numerous reefs been found, and it is only at Warrandyte that such intense contortion has taken place. It is interesting to note that where some anticlinal folds are pressed closely together, as at Ringwood and Templestowe, isolated reefs occur.

(e) *Age of the Reefs and Dykes.*

Little can be said under this head. They are both of course post-silurian, but which were formed first, or whether they were contemporaneous, cannot at present be stated. Auriferous quartz appears to have been introduced into the dykestone, subsequent to cooling, on its joint planes, but this does not relatively fix the age of the reefs, as the cross-courses and bedded veins show that the silica has been introduced at different periods. The question must for the present remain open.

(f) *Mode of Occurrence of Gold.*

As far as can be learnt, the gold is almost wholly confined to the main reefs, and in these is fairly evenly distributed when occurring in payable quantities. At the Victory mine it is said to have occurred in a wedge-shaped almost vertical shoot, and in several smaller shoots. At the Caledonia, a very rich yield was obtained from between the surface and the third level (about 300 feet). It appears to have been bounded on the bottom by a bedded vein parallel to the pitch of the rocks. Below this vein, which evidently fills an old fault plane, the gold practically ceased.

Along the top of Fourth Hill, no well-defined reef has been worked. In the coarse sandstones that outcrop on the crest of the hill, and form the cap of the Main South Anticline, much quartz has been deposited, but was evidently not very auriferous, as the sandstones have been very little worked. Most of the workings are in the eastern limb of the anticline near its axis, in shales, and the quartz veins appear disconnected. The distribution of the veins and the mode of occurrence of gold, according to old resident miners, who have personally worked at Fourth Hill, were as follows:—"Droppers" (being quartz veins two inches or three inches thick, and underlying to the west, not far from the vertical) on being followed down, would meet a bedded vein underlying to the east (the dip of the strata). At the junction, the quartz would thicken and gold would be found. The bedded vein would then be traced on the underlie for varying distances from 10 feet to 30 feet, after which it ceased to be payable, and the gold apparently gave

out. Sinking would then proceed down the "dropper" until the next bedded vein was met, when this in turn would be followed until it ceased to be payable. The bedded veins were generally about one inch thick. The "droppers" passed through the bedded veins without any faulting. The "droppers" so far as seen were not connected with any well-defined reef. This mode of occurrence was seldom found on Third Hill, and not elsewhere on the field. We have here apparently an example of the principle of intersection with deposit of gold.

Some of the conglomerate bands in the silurian have been prospected for gold, and some workings occur at Fifth Hill. Some of the miners with South African experience thought there was a similarity to the banket beds of South Africa. The writer was informed that a few ounces of gold were found in one of the conglomerates, but whether between the pebbles (as in our ordinary gold-bearing gravels), or in a reef that might pass through the conglomerate (as some do), was not clear. Evidently, however, they have not proved payable, although the determination of the point would be a matter of scientific interest.

(g) *Mining History.*

The account now given of the history of the Warrandyte goldfield is based upon the official reports of the Mines Department from May, 1859, to June of the present year. So far as the writer is aware, no official publications appeared before 1859. Those that have been used are referred to in a general way in the list of literature at the end of this paper (14). The yields stated by Mr. Forbes in his report already referred to have not been used or verified, as insufficient details are given.

According to Westgarth (15, p. 125), Anderson's Creek, Warrandyte, was the first place where gold was discovered in Victoria. Whether it was actually the first is not quite clear, but there is no doubt that it was one of the very earliest. The date is stated to be July, 1851, and £1000 was paid by the Government to the discoverers, L. J. Michel and party (16).

From 1851 to 1859, no official records are available, and therefore the portion of the mining history covered by this period cannot be touched upon.

It will be as well to distinguish between the quartz and alluvial mining. The quartz mining will be treated first.

Once the discovery of gold was made the reefs of the district were no doubt rapidly located, and any rich pockets of gold quickly obtained. After the first rush the miners must have sought the fields which have since risen to such importance—Ballarat, Bendigo, etc.—for in 1860 the Mining Surveyor refers to the numerous abandoned reefs, and the few quartz miners on the field. He considers one great drawback to the district is the want of crushing machinery, and the high price the miners have to pay for having their quartz treated, the price rising as high as £4 per ton. Several attempts were made to remedy this by the introduction of various crushing machines to the district, but none seemed to work effectively until the construction in 1868 of machinery worked by water power on the Yarra. The rates for crushing and cartage were also reduced.

A distinct impetus was in this year given to quartz mining, apparently owing to the facilities mentioned, although the crushing machinery was not very satisfactory. The impetus is shown by the yields between 1861 and 1870. From October, 1861, to June, 1868, 138 tons of quartz were crushed, yielding 153 oz. 0 dwt. 13 grs. of gold. From the latter date to the end of 1870, 725 tons of quartz, yielding 930 oz. 9 dwt. 13 grs., were crushed. There may be some exaggeration here, due perhaps to the returns in the early part of the decade not being so complete as in the later part. Making all reasonable allowance however for this possibility, the great difference between the periods mentioned remains.

During the next decade, the yield continued fairly steady. Few new reefs appear to have been discovered, the old reefs being worked by small parties with varying success. No very rich returns were obtained, those from the Pigtail Reef being the best. This reef and the Yarra Tunnel Reef were the most successful. These, together with the so-called diorite dykes, which were discovered in this decade, will be discussed separately.

During the next decade there was a serious decline. The Yarra Tunnelling Reef was resuscitated, and yielded fairly well,

but the general returns were small. This declension was probably in part due to the extraordinary wave of prosperity throughout Victoria, which culminated in the great land boom of 1888, and which drew people from a mining field such as Warrandyte.

From 1891 to 1900, the yield rose again considerably and almost equalled that of the period 1871-1880. Almost half of the yield came from the Victory Mine from three years' working.

From 1901 to the middle of 1910, the amount of gold obtained was quadruple that of the preceding decade. The yield was almost wholly due to the Caledonia Mine.

The following table shows the yield from quartz, in decades from October, 1861, to the middle of 1910, together with the tonnage, average yields and values, taken from the official records.[1]

Period.	Tons cwt.	Total yield. oz. dwt. grs.	Average per ton oz. dwt. grs.	Value.	Per oz.
1861–1870 -	863	1083 10 2	1 5 2	£4144 7/9	£3/16/6
1871–1880 -	2136	3668 16 3	1 14 8	14583/6/0	3/19/6
1881–1890 -	917	1123 11 2	1 4 12	4423 15 7	3/18/9
1891–1900 -	3731 14	3263 8 10	17 11	13054/0/0	4/0/0
1901–1910 -	13397	13135 15 0	19 14	52543/0/0	4/0/0
Totals - -	21044 14	22275 0 17	1 1 4	£88748/9/4	

These figures do not include the yields from mullock, quartz, tailings, pyrites, etc., but as some of the returns from these sources include alluvial results, no exact figures can be given. It is quite safe to state however, that the whole would not exceed £1000 in value.

The results of the working of the two dykes are also not included. As shown below, the value of the gold obtained from them is £7066.

Thus according to the official figures the total amount of gold won from quartz and the dykes during the past fifty years amounts to less than £100,000, of which, in round figures,

1 The fractions of grains have been omitted from the average yields, and the values have been calculated to the nearest ¼ oz. These returns include those from the reefs (Loyal Liberal, Growler's and Pride of the Morning) a little north of Warrandyte, which are associated with the Main North Anticline.

£51,000 was obtained from one mine, the Caledonia, in the five years, 1905-1909.

In connection with these figures it must be borne in mind that they represent the minimum gold obtained. Some yields may have been omitted from the tables owing to the difficulty of identifying the locality of various reefs. It is impossible for the officials to collect the results of all workings, and this applies more particularly perhaps to the earlier years. At the same time it is but fair to remark that the system of obtaining the returns has been in force for 50 years, and has been carried out by able officers. The results may therefore be regarded as substantially correct.

It is to be regretted that the statistics for the first ten years of the field are not available, as they no doubt would have added a fair amount to the total gold won.

The writer does not propose to attempt to deal with the history of even all the more important reefs or lines of working. Even if desired, this task is made quite impossible by the multiplicity of names of reefs and parties, from which the places where the gold was obtained cannot be determined. A few remarks however may be made about those reefs or workings which have yielded the best results or been developed the most. These are the Yarra Tunnel, Pigtail, Victory and Caledonia Reefs, and the two dykes already noticed.

The Yarra Tunnel Reef is apparently the continuation south of the Caledonia Reef crossing the Yarra, north of the island. If this be correct it is therefore on the line of the Caledonia Syncline.

In 1870 it is referred to as being worked under the bed of the Yarra, and the workings were continued till 1874 by various parties. It was then abandoned, but rediscovered in 1884, and traced northerly 900 feet. Its width is stated to be from 18 inches to 12 inches. Development proceeded, and profitable yields were obtained until 1888, when the mine was abandoned in consequence of the reef bifurcating, leaving a very thin vein which yielded poorly. The workings were to a depth of 150 feet below the river, and further shaft sinking was done, but to what depth is not stated. From 1869 to 1874 and from 1884 to 1888 311 tons of quartz were crushed, yielding 628 oz. 9

dwt. 16 grs., averaging 2 oz. and 9 grs. per ton, and valued at £2486. Almost all the gold was obtained within 100 feet of the surface. No further record of fresh workings exists.

The Pigtail Reef, which lately was worked by the Caledonia Consols Company, is first noticed in 1874, and in 1875 some rich yields are quoted—387 tons giving 1409 oz. 7 dwt., and averaging 3 oz. 12 dwt. and 19 grs. per ton. This was obtained at a depth of 80 feet and above that level. Subsequent yields came mainly from greater depths (up to 145 feet), and were not nearly so rich as those quoted. The reef was worked fairly continuously by various parties until 1881, when a slide was encountered at a depth of 170 feet. Two or three fitful attempts were made at re-working the reef, but practically nothing was done until the Caledonia Consols Company was formed. In 1905 this Company sank a new shaft to a greater depth than the old workings, and erected new machinery, including a battery. The lode was met, but was not payable. A second shaft was sunk, but the results were disappointing, and the enterprise was abandoned. From 1875 to 1881 939 tons were crushed, yielding 1882 oz. 4 dwt. 2 grs., averaging 2 oz. 0 dwt. 2 grs. per ton, and valued at £7481. Since 1881 only the sum of £614 10s. from 301 tons has been obtained from the reef, making a total recorded from this reef of £8095 10s.

The Victory Reef is on the line of the Main South Anticline, and has been worked chiefly under Third Hill. The gold yields under this name commence in September, 1896, and continue fairly regularly to September, 1899, during which period 1570 ozs. from 1038 tons, valued at £6280, were obtained. From 1899 the mine appears to have been intermittently worked until it was abandoned in 1904. Only an additional 47 ozs. are accounted for, making a total of 1617 ozs. 2 dwt. 4 grs. from 1090 tons, with a yield of 1 oz. 9 dwt. 16 grs. per ton, and valued at £6468. The yields in the early part of the period came from 100 to 150 feet in depth. The later returns do not state the depth. I was informed the shaft had been sunk about 220 feet, and a winze another 50 feet. I have no knowledge as to whether any dividends were ever paid. The mine was resuscitated as a result of the Caledonia boom under the name of the New Victory, but practically no work was done.

The Caledonia Mine (the actual name of the Company was the Caledonia Gold Mines) is situated towards the northern end of the Caledonia Syncline near the Yarra. It was formerly known as the Newhaven. The mine was worked from 1905 to 1909. According to the Annual Report of the Mines Department for 1909, the mine yielded 12,772 ozs. from 12,653 tons, the called-up capital was £8250, and the total dividends amounted to £12,583 15s. These figures determine the average per ton at 1 oz. and 4 grs., and the total value of the gold obtained at £51,088. Most of this gold was obtained between the surface and 300 feet. The shaft was sunk to 600 feet, but the stone did not prove payable, and the mine was shut down. The Caledonia yields are the one really bright feature of the Warrandyte goldfield.

The two dykes to the east of the township were discovered in 1877. The eastern one has been little worked. The rock has been decomposed to a clay, which is intersected with thin, irregular quartz veins, and contains pseudomorphs of iron oxide after pyrites. The whole of the material went to the battery. These dykes have been worked to a depth of 200 feet. They were worked continuously by various parties from 1877 to 1886. They were then discontinued until 1893, when a little work was done, and the same occurred again in 1898 and 1909, apparently without payable results. They have therefore practically not been worked since 1886. From 1877 to 1886, 22,114½ tons were crushed, yielding 1762 ozs. 6 dwt. 22 grs., giving an average per ton of 1 dwt. 14 grs., and a total value of £6959 18s. The total yield to 1909 is in round numbers valued at £7000. Considering the length of the period during which these dykes were worked, the inference is that the yield was sufficient to be payable. From the detailed figures, the dykes show a decrease in value at depth.

Some isolated yields from the quartz reefs of the field generally may be quoted:—

In Quarter ending	Locality	Quartz tons	Total Yield oz.dwt.grs.	Av. Yield oz. dwt. grs.	Depth obtained ft.
30 6 69	—Fourth Hill - - -	3½	28 2 2	8 0 14.28	140
30 9 73	—Industrial - - -	5	42 18 0	8 11 14.40	70
31 3/74	—Marble Hall - - -	3½	25 5 0	7 4 6.85	70
30/6 75	—Pigtail - - - -	141	448 17 0	3 3 16	30
31/12/75	—Pigtail - - - -	166	800 0 0	4 16 9.25	80
31 12 80	—Messrs. Sloan & Party (Fourth Hill) -	11	249 12 0	22 13 19.64	30-35
31 3 81	—Messrs. Sloan & Party (Fourth Hill) -	4	29 10 0	7 7 12	35
31/3/83	—Young Colonial - -	3	28 18 0	9 12 6	40
31 3/85	—Yarra Tunnelling - -	28	121 4 20	4 6 14.43	80
30/6 92	—Black Swan - - -	22	106 13 0	4 12 9.4	40
30/6/95	—Messrs. Blair Bros. - -	2½	37 2 0	14 16 19.2	—
31/3/96	—Messrs. Dixon & Holloway	3	27 14 1	9 4 16	60
31 3/96	—Messrs. H. Squires & Party	3	88 0 0	29 6 16	—
30/9/96	—Victory - - - -	4	29 12 0	7 8 0	100

The results from alluvial mining cannot be given. No regular returns can be obtained. Instances are recorded of various rich finds, but nothing definite can be stated as to the workings as a whole.

From the general reports of the Mining Surveyors and Registrars, the gullies and creeks tributary to the Yarra at Warrandyte have not been very profitable. The best returns have been from the bed of the Yarra itself. The river was in the early days dammed and paddocked so as to reach the gold, and the results in general are stated to have been satisfactory. In later years further efforts were made, but without success. The bulk of the gold had apparently been obtained by the earlier miners.

Two undertakings, on account of their magnitude, deserve to be mentioned. One is the cut through the river at the bend known as Thomson's Bend, near Parson's Gully, by which an island was formed, and the other the tunnel through the rocks at Pound Bend, connecting the river at two points. The object in each case was to divert the river from the bend, and obtain the gold from the river bed.

The cut at Thomson's Bend was begun in 1859, and completed in 1860. The river was diverted through the new cut, and the old bed laid dry. Difficulties were encountered by the

river breaking through the dam. No details of the results are given, but as the enterprise soon ceases to be mentioned by the Mining Surveyor it was presumably a failure.

The tunnel was successfully made at the Pound Bend in 1870, and the river diverted through it. Trouble arose through the river finding a new course. This was repaired, but as no definite results are stated, and mention of the scheme soon ceases, this must also be regarded as a failure, although gold in patches is stated to have been distributed all round the bend. Each undertaking must have been expensive.

(h) *Possibilities of Further Development of Quartz Mining.*

There are two phases to this question. First, whether any horizontal extension of the field is likely, and secondly, the prospects of payable stone at greater depths than hitherto worked at the present-known reefs.

The first aspect must be answered in the negative. The geological structure of the field indicates a close connection between the highly folded area and the quartz reefs. This area is limited to Warrandyte, so that beyond it, the fractures necessary for the formation of the reefs would not be expected, and, so far as observation goes, this is correct.

Mr. Moon, on the Quarter Sheet already cited, and Mr. Whitelaw on his map of part of Nillumbik Parish, show a moderate number of quartz reefs outside the Warrandyte area. The writer has not seen all these reefs, but those inspected, so far as could be seen, are thin, irregular, and generally in localities where the geological structure of the country does not favour any system of fractures. Some of these reefs have been slightly opened up, but the prospects were evidently unfavourable. The development of some of them may also have been hindered by being on private property, and some may exist that if worked would be payable. Gold has been found in gullies on the northern side of the river at Warrandyte. This may have come from isolated reefs, or the dykes, or from the gravels under the basalt at Kangaroo Ground, or from all three.

Allowing, however, for these possibilities, the structure of the country surrounding Warrandyte does not support any hope of a substantial extension of the present, or of the discovery of a new goldfield.

The second phase of the question is more difficult to deal with. Extensive shallow workings exist along the line of the Main South Anticline from the Great Southern Reef to the Yarra, but their history is not fully known. The same may be said of most of the other workings on the field. Throughout the official records there is scarcely a hint as to the mode of occurrence of gold, nor any light as to its origin and distribution. At the time of the writer's visit to Warrandyte, only one mine—the Caledonia—was working, and from that no gold was being obtained. Thus there is little to help the question.

Most of the workings show that further effort was abandoned when the level of ground-water was reached. The depth at which the gold was obtained is recorded in the official returns to 1898 fairly completely, and these show conclusively that the great bulk of the gold was found at and above 150 feet below the surface, and most of this within 100 feet from the surface.

Most of the gold therefore up to 1898 was found within the zone of oxidation or vadose zone. Since 1898 the Caledonia and the Victory are practically the only mines that have been working. The Victory went below the water-line, and some of its gold may have come from there. At the Caledonia the level of ground-water is near the surface, and the bulk of the gold came from below that level—i.e., from the (probably enriched) sulphide zone.

It is important to determine for the point under discussion whether the reefs are likely to prove permanent in depth and whether secondary enrichment has taken place. As regards the former, although the reefs are thin, there is ground for believing that they continue in depth. The minor folds are clearly defined, and there is no reason to doubt that the fractures which accompany them descend some distance. At the 600 feet level of the Caledonia the reef became very thin, but there was a roll to the east, which would probably account for its pinching in. I was told that it became a strong reef again below this level, when it had its normal underlie again.

The Yarra Tunnel Reef was abandoned on account of its bifurcation, but this does not necessarily prove that it may have met and thickened again lower down.

Secondary enrichment has probably taken place in the reefs here, both in the vadose zone generally and in the sulphide zone at the Caledonia. The geological structure shows the vast amount of silurian strata removed from the surface of the ground at Warrandyte. The reefs must have extended upwards into these rocks, and in the denudation of the latter, the former would be removed, and if gold-bearing, would tend to enrich the undenuded parts of the reefs. There appears to be no doubt, from the general returns, that near the surface the reefs and also the dykes are richer than the lower portions worked, both in the sulphide zone of the Caledonia, and the vadose zone generally.

So far as can be determined, therefore, the reefs may not maintain their yield at depth, but as the sulphide zone below the oxidation zone is often enriched at or a little below the latter, it is possible that some reefs may have benefited in this way. Apparently the only reefs given anything of a trial in this direction are the Consols and the Victory, and they have not proved payable, so that experience gives no support to the idea. The Caledonia cannot be taken as a fair test of the enrichment of the sulphide zone, as there appears to be so little of the oxidised zone above the former to absorb the gold.

Again, one of the dykes previously referred to crosses the Yarra close to the Caledonia. It is possible that the gold in the Caledonia may have been leached out from this dyke. The other reefs are some distance from the dyke, and may, therefore, not have benefited by it. Considering all the evidence, the probabilities are, therefore, against the maintenance of the yields in depth, but this does not exclude the possibility of shoots of gold in some reefs which, if worked with strict economy and care, may be found payable at greater depths than at present worked.

Summary.

The paper deals with the silurian rocks of a wide area of country in the basin of the Yarra.

The rocks are shown to consist chiefly of shales and sandstones, with a series of fossiliferous grits and conglomerates at Warrandyte.

The geological structure of the silurian consists principally of a great arch or geanticline at Warrandyte, on the top of which are a series of minor folds, with which are associated the conglomerates and grits, and a series of auriferous quartz reefs. This fold is known as the Warrandyte Anticline. It extends from Tunstall to Watson's Creek, and its axial line is broken at Warrandyte. To the south and north of Warrandyte it breaks into more normal folds, which are described. To the west of the Warrandyte Anticline is the Bulleen Syncline, a great feature traced some distance north and south. Farther west is the Templestowe Anticline. Various dykes are associated with the rocks.

The evidence of faults and peculiarities of joints in the silurian is discussed, including the smooth fracture of conglomerate pebbles.

The conditions of sedimentation in the silurian are referred to.

The age of the silurian rocks cannot be settled until the fossils are examined. On field evidence alone, the oldest beds are at Warrandyte, and the youngest at the Bulleen Syncline, and to the north of Croydon.

The thickness of the western leg of the Warrandyte Anticline is estimated at between 12,000 and 13,000 feet, and that of the eastern at between 14,000 and 15,000 feet, while the vertical height of the silurian removed from above the Warrandyte Anticline is probably over 12,000 feet.

The rocks from which the silurian conglomerates were derived are shown to be altered and unaltered sedimentary rocks.

The Warrandyte goldfield is shown to be due to a series of minor folds on the top of the Warrandyte Anticline, which have fractured and so admitted the silica and gold. The distribution of the quartz reefs is noted, and their relation to the folds and the dykes to the east is discussed. The conclusion is drawn

that the horizontal limitation of the goldfield is due to the limitation of the minor folds (most of which rapidly merge into one fold).

The mode of occurrence of gold, a general account of the mining history, and the possibilities of further development of quartz mining are referred to.

A list of the literature referred to is given.

In conclusion, I wish to express my thanks to Prof. Skeats for advice and criticism in connection with my work. I have also to thank the respective permanent heads of the Lands and Mines Departments for the use of maps, and for permission to inspect some unpublished returns of gold, the access to which was facilitated by Mr. D. J. Mahony, of the Geological Branch, and Mr. D. Wallace, of the Statistical Branch, to both of whom my thanks are due. My brother, Mr. C. A. Jutson, was also good enough to compile the table of gold returns for the various decades, the data for which I am, however, alone responsible. I have also to thank Messrs. F. Trezise, J. Sloan, H. and F. Squires, of Warrandyte, for information relating to the mines there.

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EXPLANATION OF PLATES.

Plate XCI.

Sketch map of the whole or parts of the Parishes of Nillumbik, Sutton, Warrandyte, Ringwood, Bulleen and Nunawading, compiled chiefly from the parish maps. The basalt at Kangaroo Ground is not shown, as the map is intended only to illustrate the general geological structure of the silurian rocks of the district. The results only of the survey are indicated, as the scale of the map precludes any adequate detail being set out.

Plate XCII.

Enlarged map of, and section across, the Warrandyte goldfield. All available details are not shown.

Plate XCIII.

Sections illustrating the general geological structure of the country comprised in Plate XCI. In these sections, and in that on the Warrandyte goldfield map, the datum line is sea-level.